3D SSD CONTROL ON LEFT-TURN CURVES OF FREEWAYS OVERLAPPED WITH VERTICAL CURVES

Stergios Mavromatis, Assistant Professor

Technological Educational Institute of Athens

stemavro@teiath.gr

Basil Psarianos, Professor

National Technical University of Athens

psari@survey.ntua.gr

Fotis Mertzanis MSc, PhD Candidate

National Technical University of Athens

fmertz@central.ntua.gr

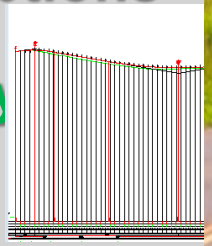
Sophia Vardaki PhD, Senior Researcher

National Technical University of Athens

sophiav@central.ntua.gr

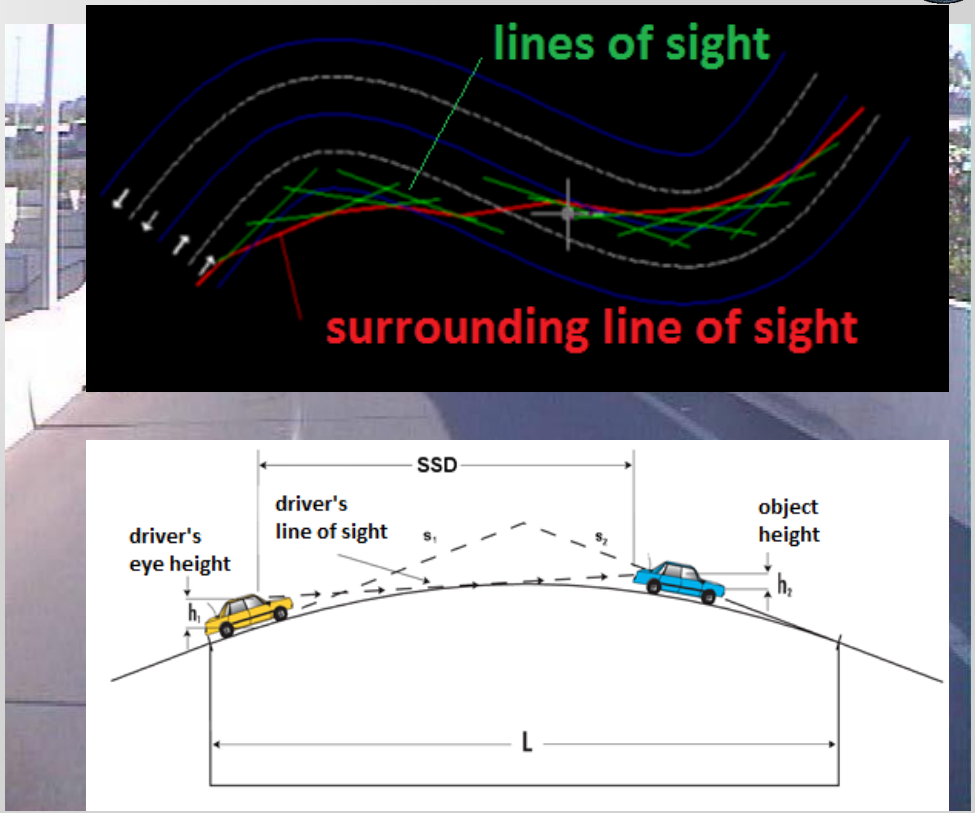
3D Highway Geometry

- 2 Independent and Mostly Uncorrelated 2D Stages
  - horizontal alignment
  - vertical alignment
- 2D Approach Associated with Design Misconceptions that Influence Design Performance Adversely
  - typical case: SSD



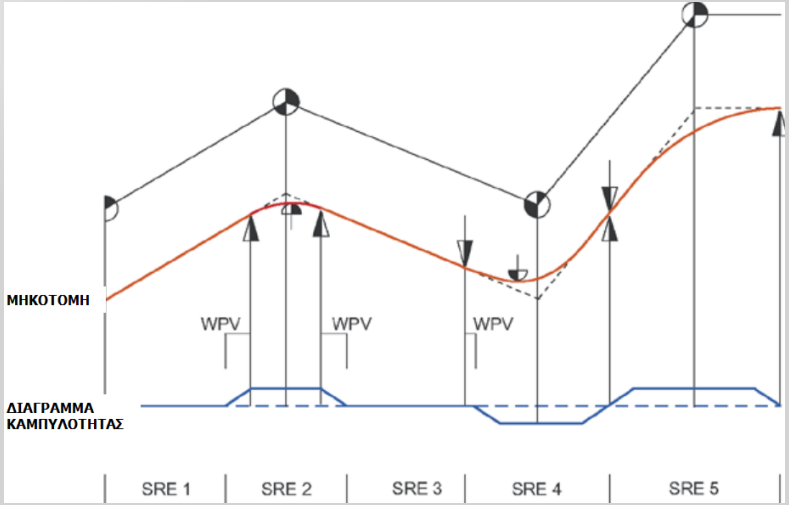
2D SSD Calculation

- Inexact
- Fragmentary
- May Produce Design Deficiencies
- May be Detrimental to Cost, Performance and/or Safety of Divided Highways



Current Practice

- **2D Approach**
  - efforts to overcome this incorrect SSD determination
    - ✓ establishing some coordination between the horizontal and vertical curve positioning
  - not all design cases are addressed

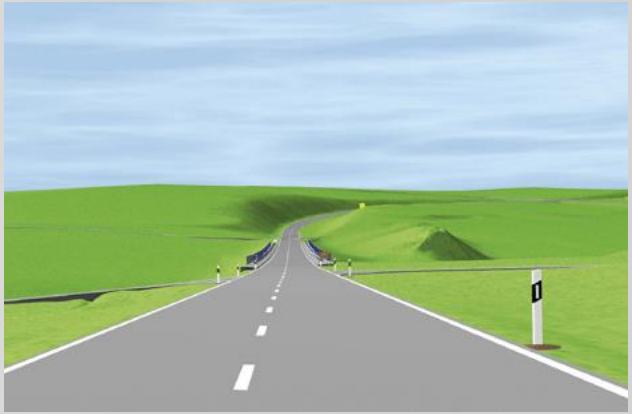


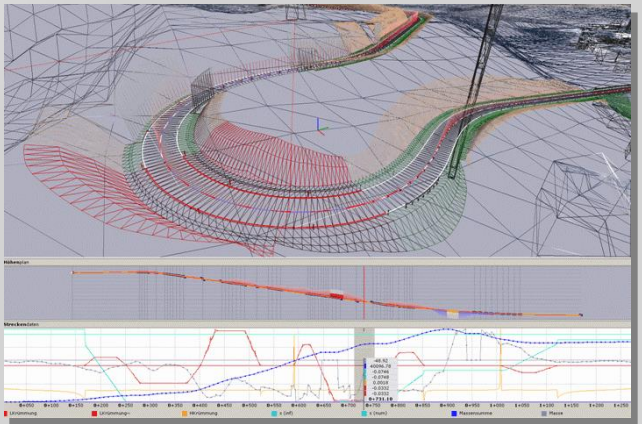
Current Practice on Left Curved Divided Highways

- **Necessity for SSD Adequacy Emphasized**
- **No Explicit Process Provided**
  - $SSD_{AVAILABLE}$ defined by lateral clearance and curve radius
    - ✓ valid for circular curves longer than the sight distance assuming both driver and obstacle positioned on circular curve
    - ✓ no assurance whether barrier height and/or the presence of vertical curve do not obstruct driver's line of sight

SSD Modeling

- **3D Models**
  - capable of simulating accurately compound road environments (3D)
  - allow the definition of actual vision field to driver (3D)
  - focused in optimizing the available SSD introducing
    - ✓ new algorithms
    - ✓ design parameter combinations





Objectives (1/2)

- Deliver Reliable Tool for SSD Assessments
- Simulate During Emergency Braking Conditions via 3-D Perspective Concurrently
  - alignment design
  - vehicle dynamics

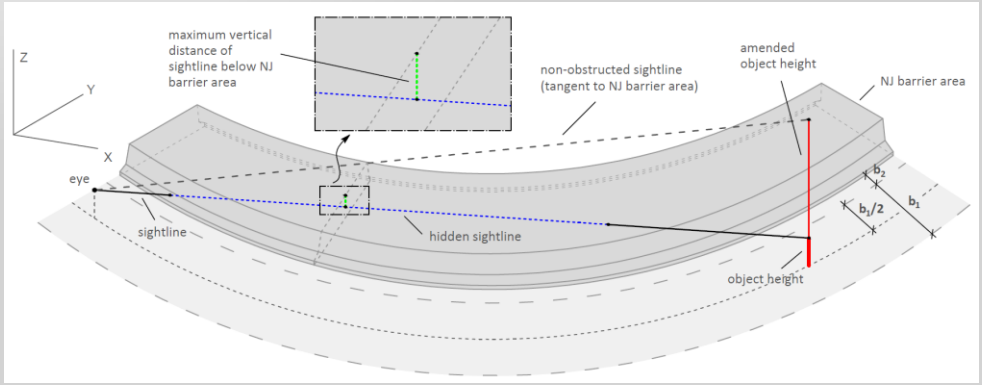
Objectives (2/2)

- **Define Areas where Arrangements of Crest Vertical Curvature on Horizontal Circular Alignments Generate SSD Inadequacies**
  - quantify the safety impact
  - provide possible realistic solutions based on existing design parameter selection associated to SSD

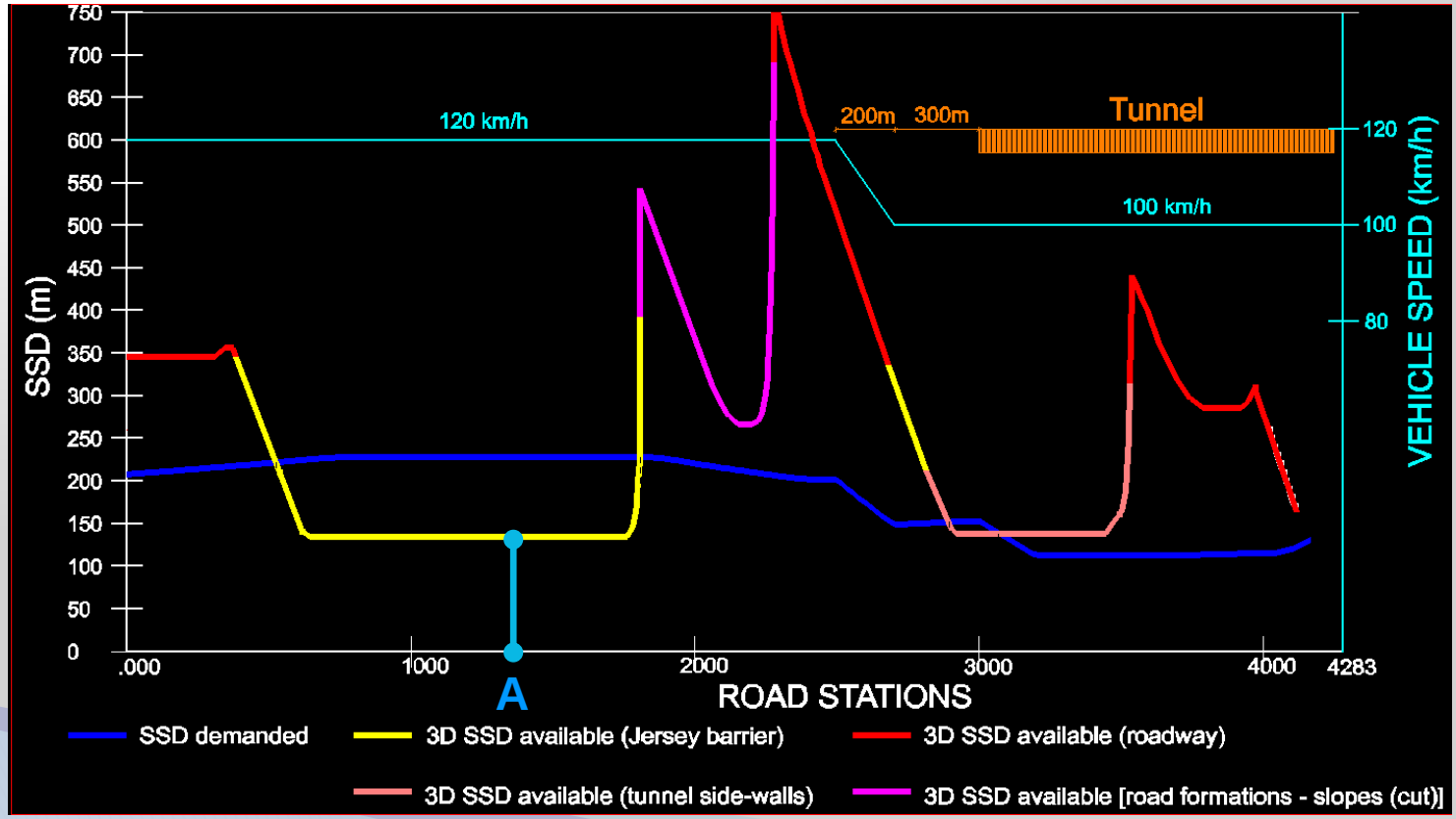
SSD Modeling Proposal

$SSD_{DEMANDED} \leq SSD_{AVAILABLE}$

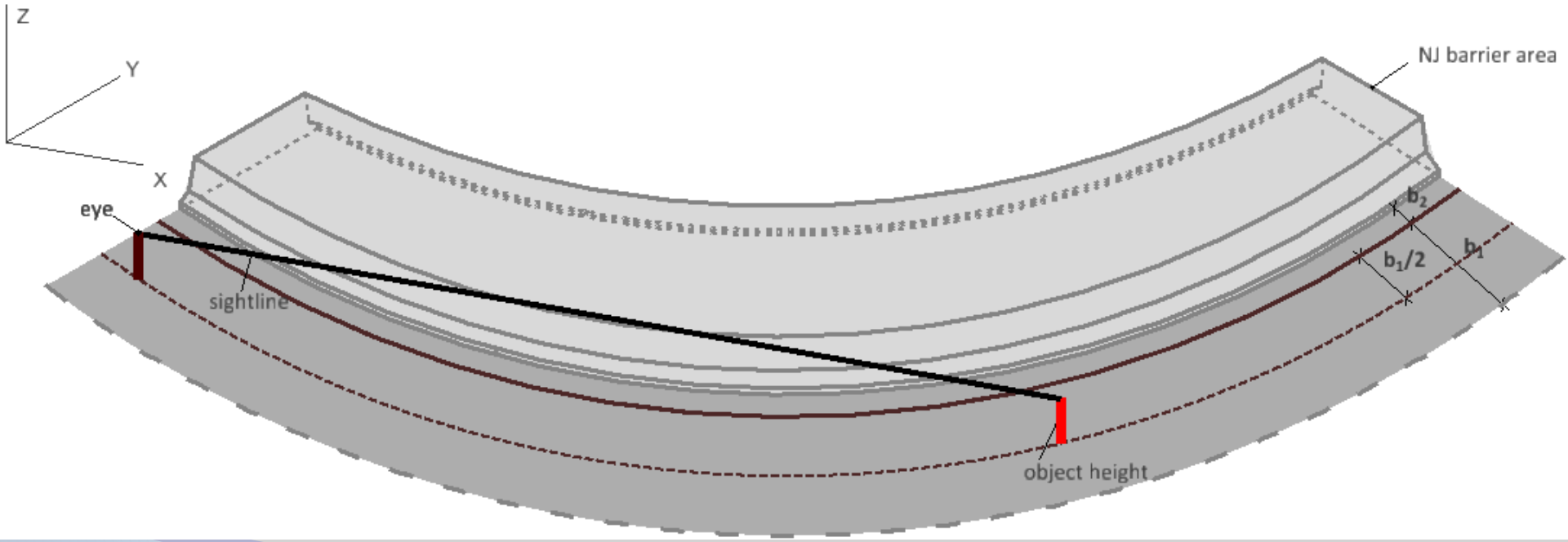
- $SSD_{DEMANDED}$
  - enriched point mass model
    - ✓ actual values of grade (vertical curves)
    - ✓ friction variation (vehicle cornering)
- $SSD_{AVAILABLE}$
  - driver's line of sight towards object height
    - ✓ at certain axis offset
    - ✓ 3D roadway environment



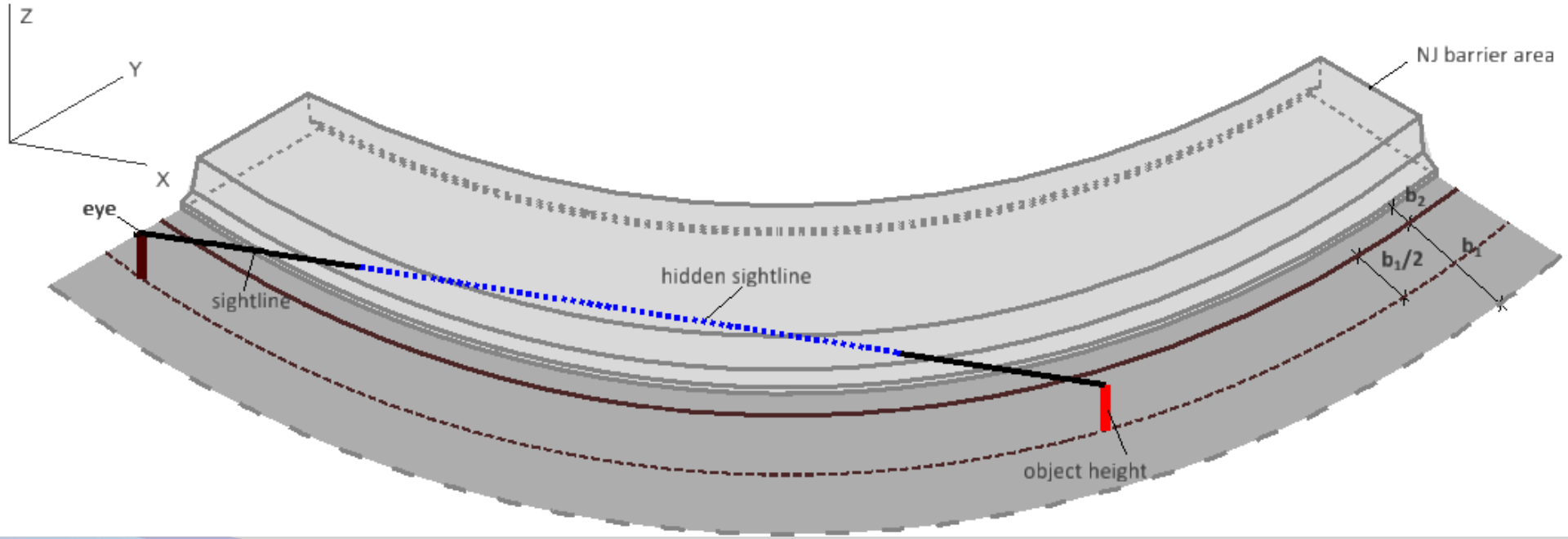
SSD Modeling (existing approach)



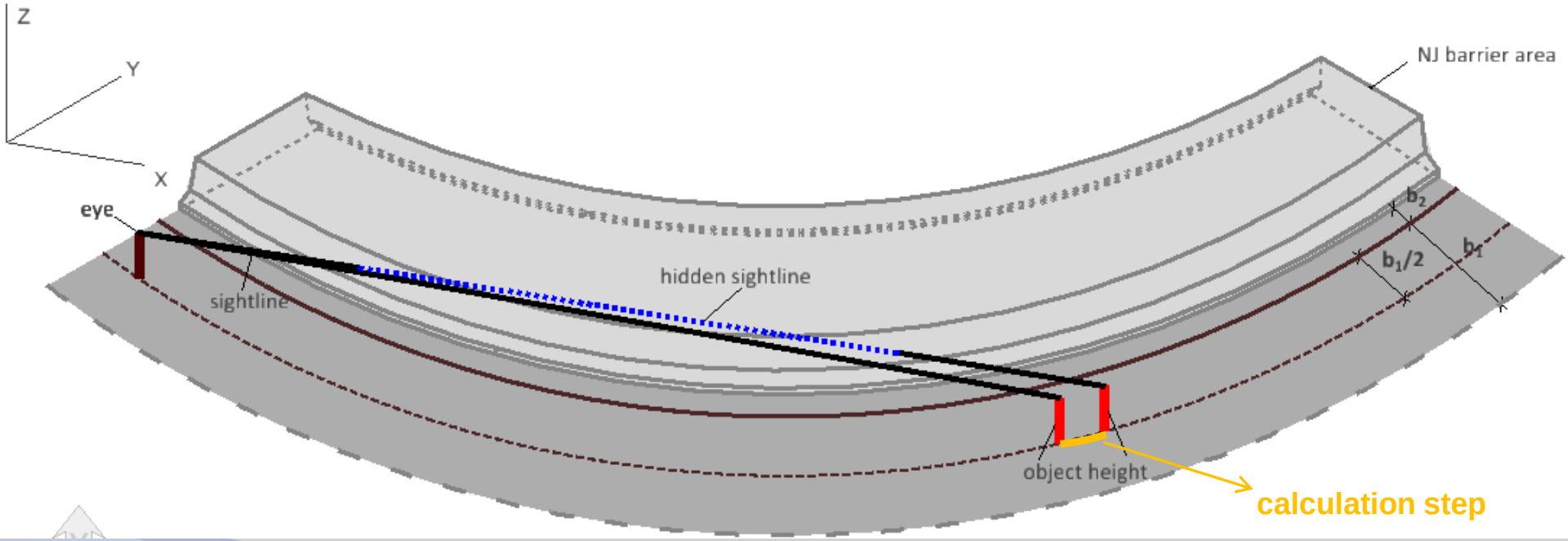
$SSD_{AVAILABLE}$ (Station A)



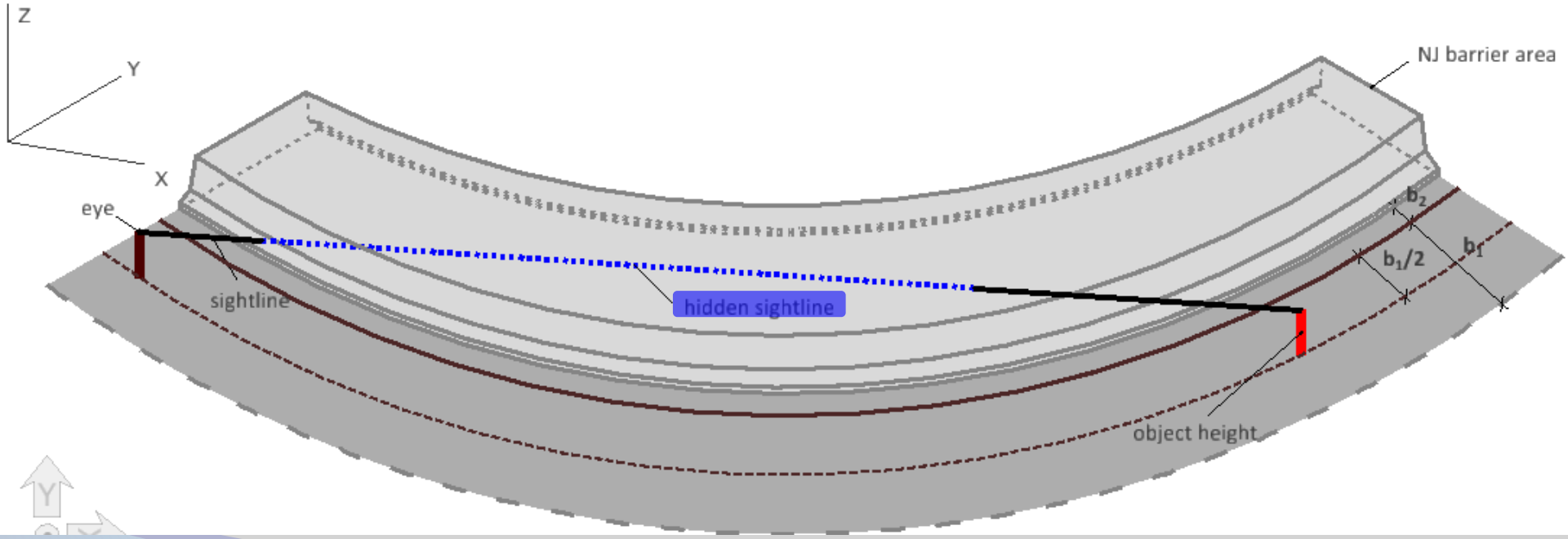
$SSD_{AVAILABLE}$ (Station A + calc. step)



$SSD_{AVAILABLE}$ (Station A) VS $SSD_{AVAILABLE}$ (Station A + calc. step)

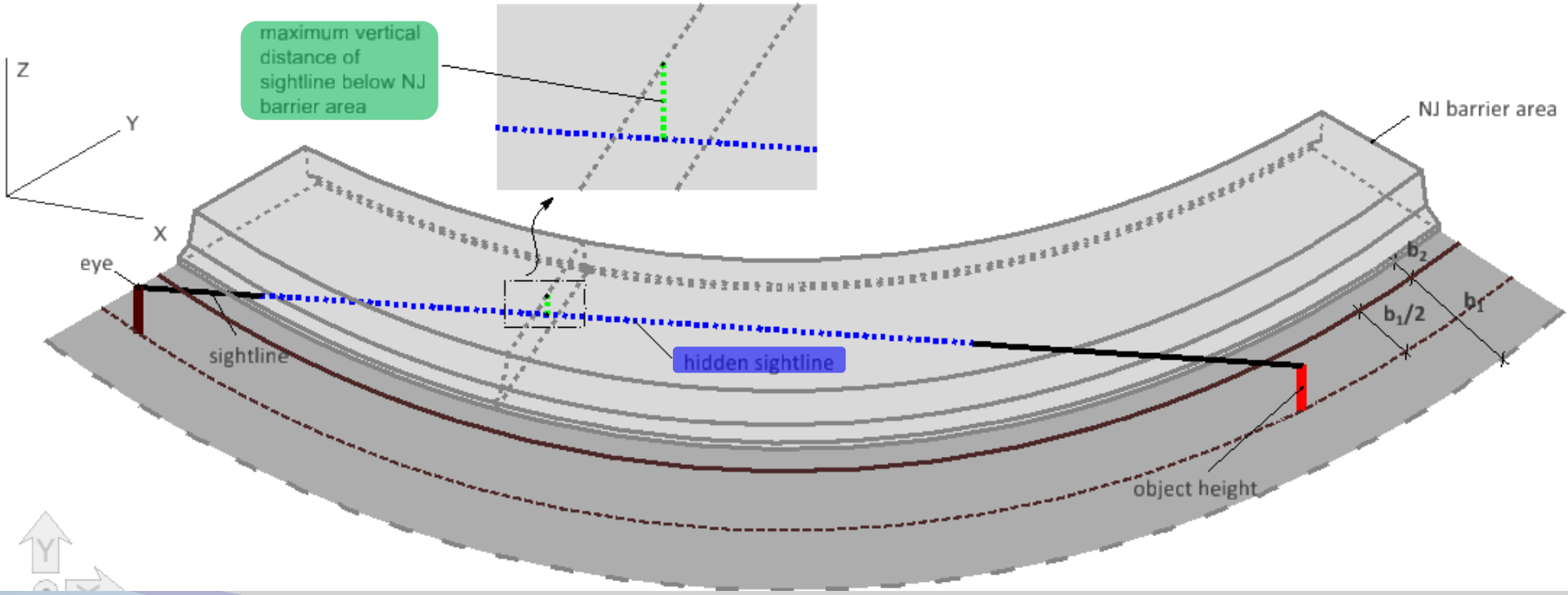


SSD Modeling Proposal (1/3)



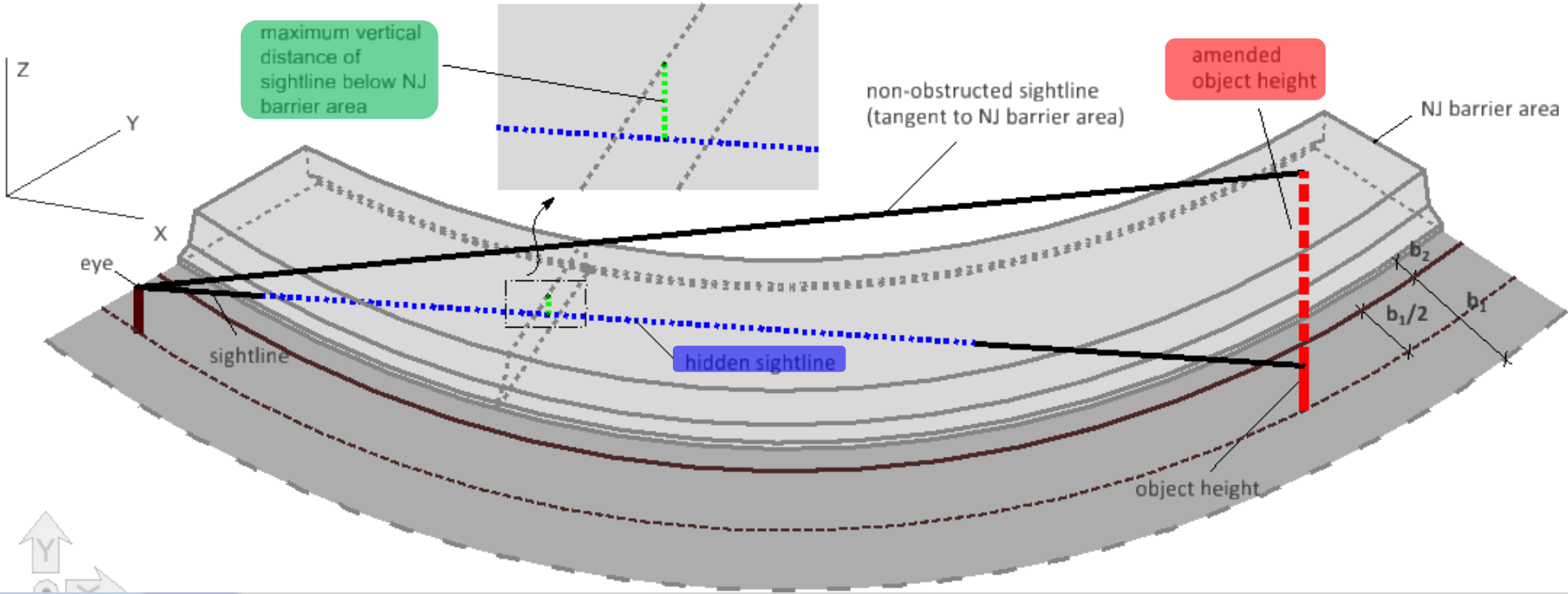
$$SSD_{DEMANDED} = SSD_{AVAILABLE}$$

SSD Modeling Proposal (2/3)



$$SSD_{DEMANDED} = SSD_{AVAILABLE}$$

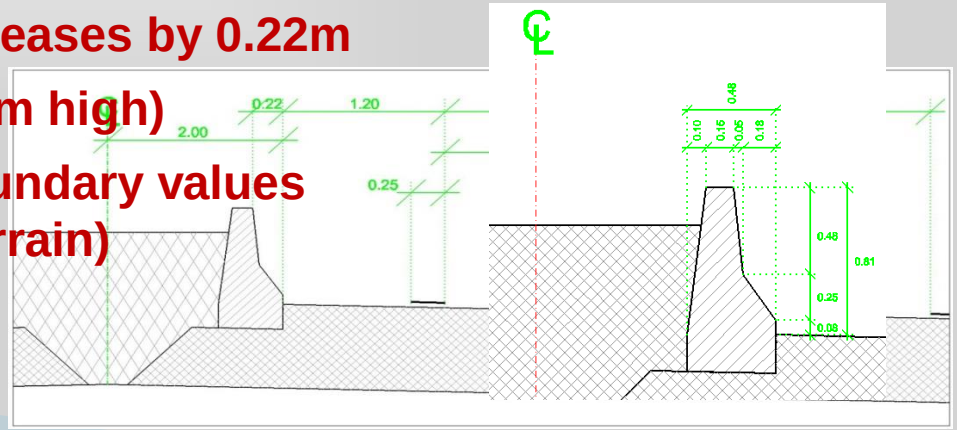
SSD Modeling Proposal (3/3)



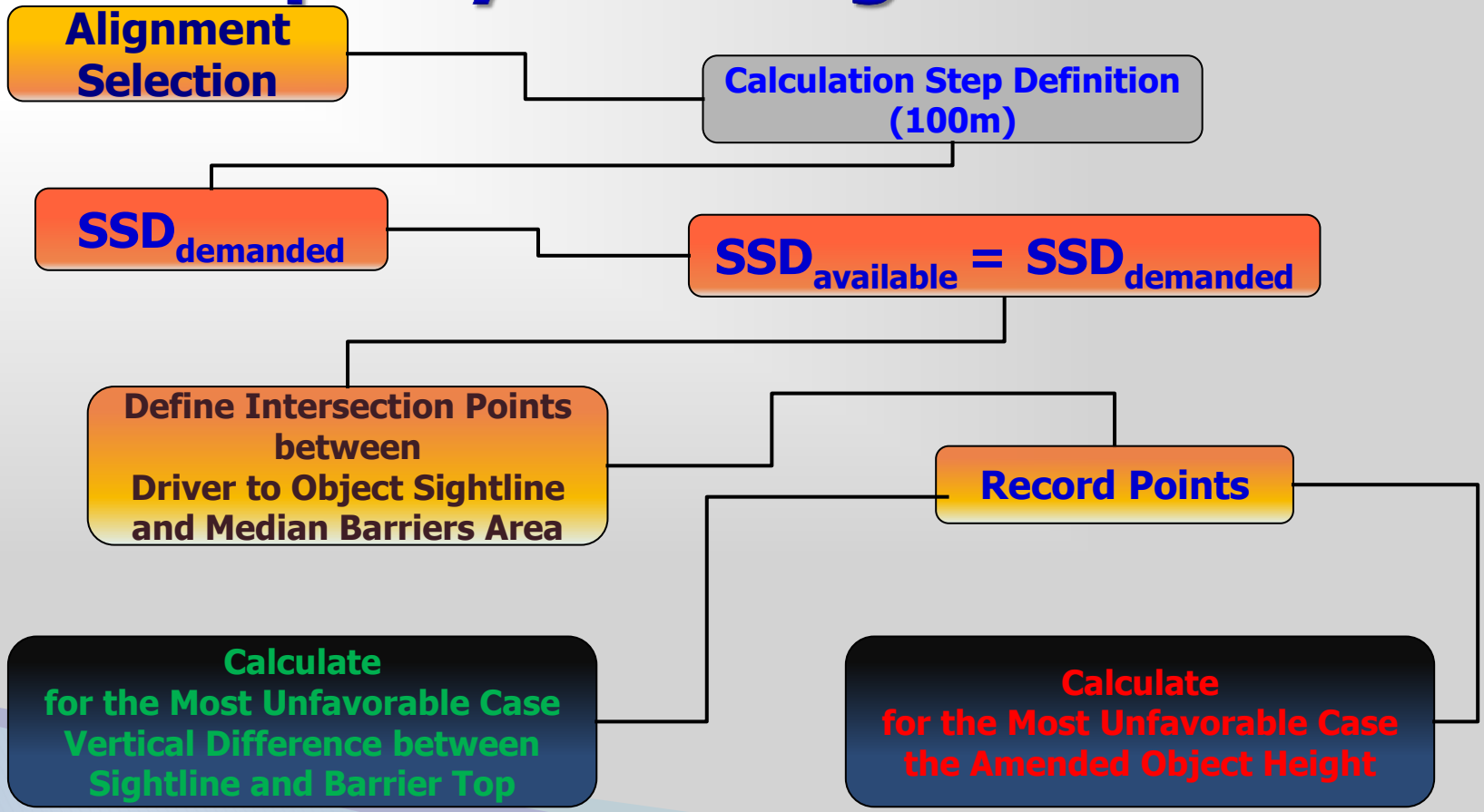
$$SSD_{DEMANDED} = SSD_{AVAILABLE}$$

3D SSD Adequacy Investigation on Left Curved Divided Highways

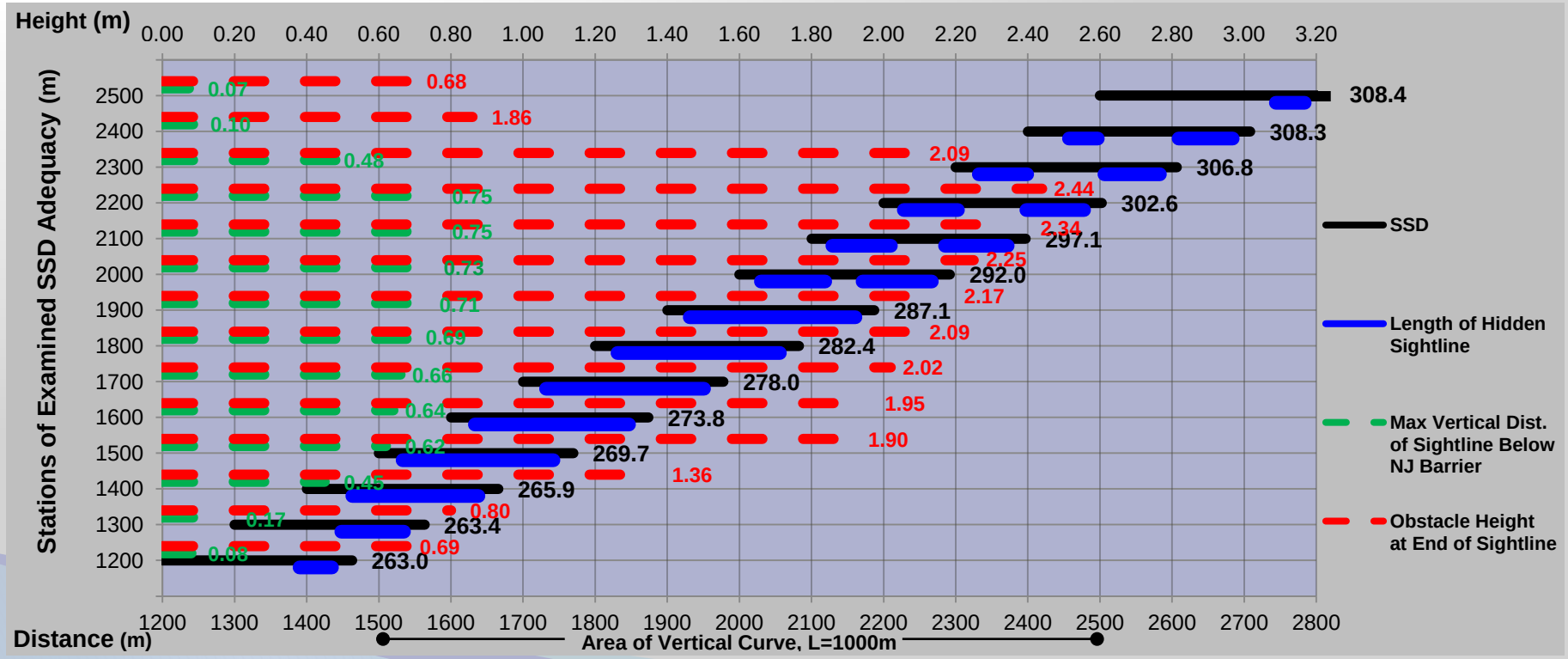
- **AASHTO 2011 Design Guidelines**
  - V_{design} =130km/h
  - variety of horizontal – vertical parameters
    - ✓ passing lane 3.60m
    - ✓ inner shoulder width = 1.20m
    - ✓ NJ curvature at top increases by 0.22m
    - ✓ NJ median barrier (0.90m high)
    - ✓ crest vertical curve boundary values +4% and -4% (rolling terrain)



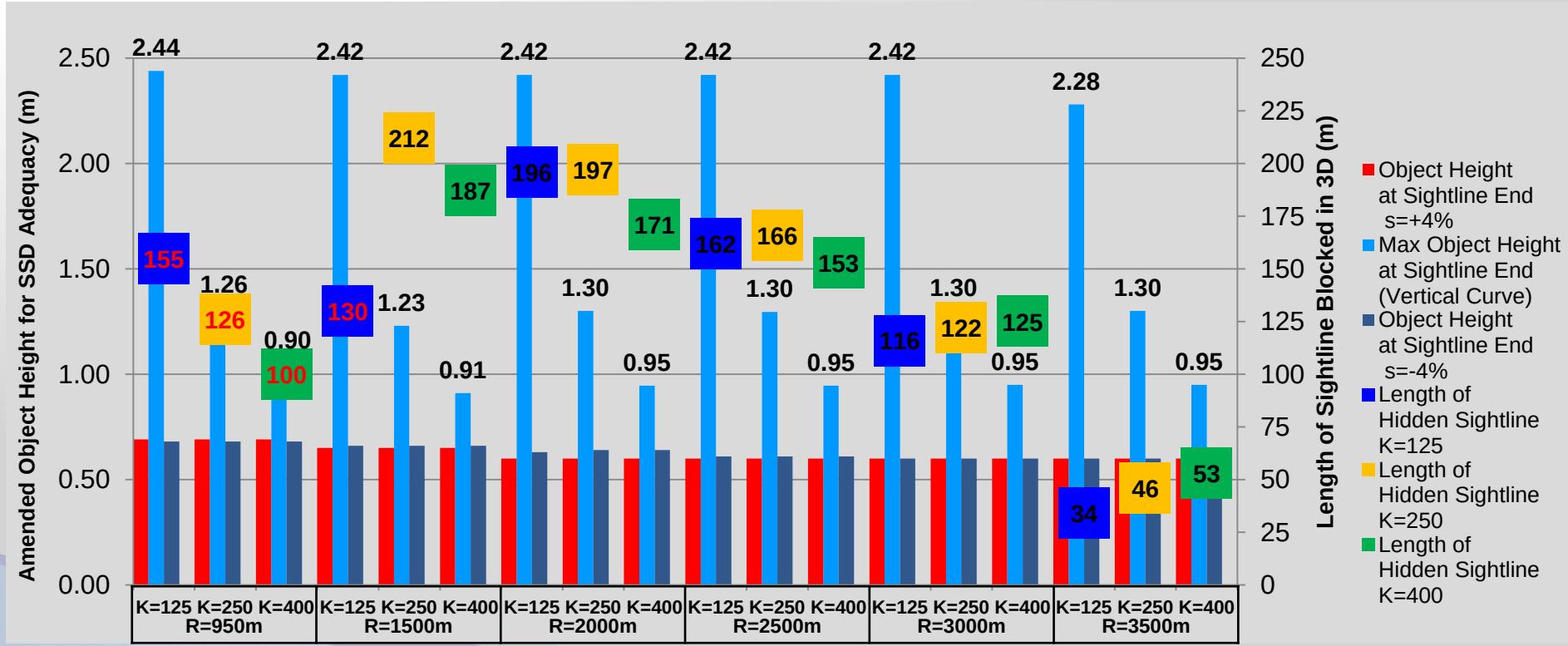
SSD Adequacy Investigation



Output Data (R=950m, K=125m)



Output Data (18 alignments)



Percentage Reduction of $SSD_{available}$ to Retain OH=0.60m

Horizontal Radius (m)	Crest Vertical Curvature Rate (m)		
	125	250	400
950	> 48%	> 48%	> 48%
1500	> 35%	> 35%	> 35%
2000	> 25%	> 25%	> 25%
2500	> 16%	> 16%	> 16%
3000	8%	9%	9%
3500	1%	1%	2%

Can We Reduce $SSD_{demanded}$?

- In Current Practice SSD Parameters
  - based on experience
  - do not represent entire passenger vehicle fleet
- Introduction of:

"tolerable road length not visible to the driver"

Tolerable Road Length Not Visible to the Driver

- $SSD_{available} = SSD_{demanded}$ Reduced by 10%-12%
  - SSD reduction suggestions, according to which the current deceleration rate of 3,7m/sec^2 can be increased to 4.3m/sec^2
    - ✓ incorporate improved braking performance of modern vehicles (ABS, etc.)

Reduction of SSD by 10%-12%

Horizontal Radius (m)	Crest Vertical Curvature Rate (m)		
	125	250	400
950	> 48%	> 48%	> 48%
1500	> 35%	> 35%	> 35%
2000	> 25%	> 25%	> 25%
2500	> 16%	> 16%	> 16%
3000	8%	9%	9%
3500	1%	1%	2%

- **Still SSD Inadequacy for R<2700m**
  - inner shoulder width = 1.20m

Increase Object Height!!!

- Set Object Height = Driver Height
- Vehicle Tail Lights Height = 1.08m
- Based on FMVSS, Stop Lamp Heights of Passenger Cars Fall Between 38cm – 183cm
- Benefits while Performing SSD Assessment
  - consistency of the design and driver's expectations can be satisfied in terms of
    - ✓ avoiding ununiformed posted speed areas

      or/and
    - ✓ unsuitable lateral road broadenings

    where in each case safety violations might occur as well

Percentage Reduction of $SSD_{available}$ to Retain OH=1.08m

Horizontal Radius (m)	Crest Vertical Curvature Rate (m)			
	125	250	400
950	37%	11%	0%
1500	35%	11%	0%
2000	25%	11%	0%
2500	16%	12%	0%
3000	8%	9%	0%
3500	1%	1%	0%

- **Arrangements of Design Elements (V_{design} =130km/h, ISW = 1.20m)**
  - K=125m for R>2800m
  - R=950m for K>250m

Conclusions

(1/3)

- **SSD Adequacy Investigation**
  - passing lane of left-turn freeways with compound alignment
  - $SSD_{DEMANDED} \leq SSD_{AVAILABLE}$
- **Potential Safety Violation for AASHTO 2011**
  - V_{design} =130km/h
  - inner shoulder width = 1.20m

Conclusions

(2/3)

- **Extensive SSD Shortage Areas for Control Horizontal and Vertical Design Values**
- **Various Compound Alignments Examined**
  - **by broadening the horizontal curves, the conflict area formed by the sight line intersection against the median width increases as well**
    - ✓ **resulting in relevant vertical curve radii raise**

Conclusions

- ***"Tolerable Road Length Not Visible to the Driver"***
  - **length of the demanded SSD reduced by 10%-12%**
    - ✓ **SSD adequacy R>2700m**
- **Necessity of Increasing Object Height to 1.08m (vehicle tail lights = driver height)**
  - **most optimal mean to avoid extensive design and operational interventions**

Further Research

- **Additional Work**
  - examine more speed values
  - optimize in terms of SSD provision, the influence of additional parameters
    - ✓ inner shoulder width
    - ✓ median barrier type for every utilized case (bridge, tunnel areas, interchange ramps etc.)
  - assess night time driving conditions
  - investigate human factor